GREENWICH OBSERVATORY.

By JAMES CARPENTER, F.R.A.S.

THERE are few scientific institutions whose objects are so little understood, and whose labours are therefore so likely to be misjudged, as an astronomical observatory of the character of the national one at Greenwich. Even those who possess some knowledge of astronomy, who read its literature, and take a warm interest in its salient achievements, are frequently little or not at all conversant with those departments of the science that are perforce pursued in an essentially practical establishment, where the sun may be observed day by day without a moment's thought being given to his spots, the moon watched by night without a care for her physiography, and where the planets and stars are subjects of a system of close observation which, however, gives no heed to questions concerning their physical nature.

It happens, from a circumstance that will bye-and-bye appear, that the present is an opportune time for reviewing the history of the Observatory at Greenwich and its relation to current astronomical science; but it may be mentioned that the appearance of this article at this opportune time is merely accidental.

To start with a just idea of the very definite aims of the Observatory, we should clearly recognise the circumstances that led to its foundation. It was born of a necessity that arose from that extension of British navigation which was, at least partially, a consequence of the passing of the Navigation Act of Charles II. The necessity was a means of obtaining the longitude at sea. The latitude, we may remark, presented no difficulty whatever. A method for longitude had for more than a century existed in theory; for Apian in 1524, Gemma Frisius a few years later, and Kepler subsequently, had proposed the use of lunar distances in the very form that now universally obtains. The method may be thus described. The moon moves rapidly among the stars. Suppose that for a given instant of Greenwich

time her angular distance from a near star be known beforehand. Then if an observer at sea measure the distance minute by minute till he makes an observation which shows the distance * equal to the given one, he knows the Greenwich time for the moment of that observation; and this time compared with the local or ship's time of the observation gives, by mere difference, his longitude reckoned, in time, from Greenwich. If the distance of moon from stars be given at fixed intervals of Greenwich time, say hourly,† then it matters not when the navigator takes his distance, for he can always find, by interpolation, the instant of Greenwich time corresponding to the moment of his observation.

Now, to make this method practical two things are necessary. First, the positions of the fixed stars must be exactly known; and second, the moon's place hour by hour must be accurately predictable a long time in advance, so that the mariner may carry the table of predicted Greenwich distances out with him. The plan, as we have said, was proposed more than three centuries ago, and the need of applying it was severely felt just two centuries ago. But there were no catalogues of fixed-star plans accurate enough for the purpose; and the knowledge of the moon's motions was utterly insufficient also. The double want was brought to the King's (Charles II.'s) notice, and he at once ordered an observer to be appointed and an observatory to be founded to meet it. The right man for the post turned up in the person of Flamsteed, and he was commanded forthwith to "apply himself with the utmost care and diligence to the rectifying the tables of the motions of the heavens and the places of the fixed stars, so as to find out the so-much-desired longitude of places for the perfecting the art of navigation." The same object is set forth in the tablet which still stands over what was the entrance-door of the building; and a wording almost identical with that just quoted has been maintained in the warrants of all succeeding Astronomers Royal to the present day.

It is desirable that this definition and its implied limitation of the duties of the Observatory should be borne in mind. There is no provision in its charter for the numerous modern subjects of inquiry which have been classed under the head of *astronomical physics*. It is true such subjects have been occasionally followed up, but only to an extent that precluded

* Certain corrections are necessary to reduce the angular distance as measured at the earth's surface to what it would be if measured from the earth's centre; but these form part of the after calculation.

† As a matter of fact, they are given for every third hour in our "Nautical Almanacs."

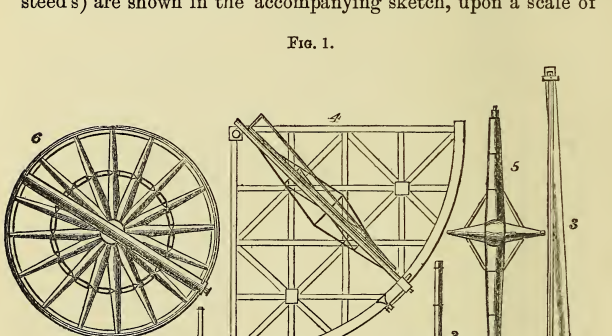
interference with the primary objects of the institution. From first to last Greenwich has been held to be an institution for the pursuit of mensurative astronomy with utilitarian ends, and its instruments, and, to some extent, its *personnel*, have been provided and organised accordingly. The succession of Royal Astronomers—Royal Observators, as they are officially styled—Flamsteed, Halley, Bradley, Maskelyne, Pond, and the present occupant of the office, have, with one exception, laboured with a consistency truly remarkable, like one long-lived man, to carry out, with the best resources of their times, the strictly fundamental works committed to them: with what results we shall presently see.

Positions of stars for the formation of catalogues of star-places, and positions of the sun, moon, and planets for the ultimate formation of tables of their motions, are the staple observations at Greenwich, and they consist almost entirely of meridian observations, namely, times of transit over the meridian, for determination of objects' Right Ascensions, and measures of the angular distances of the same objects from the celestial pole, for the determination of their North Polar distance; these last being also made on the meridian. The instruments for these observations are the "Transit" and some form of "Circle," both instruments moving in the plane of the meridian only, and the first having it accurately defined by a vertical wire, in modern times a cobweb thread. Flamsteed at first had a make-shift sextant, with which he could only measure one star from another in a straight line, and he had to leave these measures to be ultimately referred to fixed points for determination of Right Ascensions and Polar Distances. But in 1689, thirteen years after his appointment, he procured —from his own resources, by the way, for from first to last he never had a penny for instruments from the Government—a large graduated arc, which was fixed upon a wall in the meridian plane, and upon the centre of which was pivoted a telescope with a vertical wire at its focus; and he took clock-times of transit across this wire for Right Ascension, and read the position of the telescope upon the arc for Polar Distance. Halley had a transit instrument, with a $1\frac{3}{4}$-inch object-glass, generally similar in plan to those of the present day, specially for R.A. observations, and a meridianal quadrant of 8 feet radius specially for those in Polar Distance. Bradley at first had Halley's instruments, afterwards a better transit of $2\frac{3}{4}$-inch aperture, and a second quadrant, so that he could command the whole meridian from the North horizon to the South. Maskelyne used Bradley's instruments from first to last, but the defects of a quadrant, in its liabilities to distortion and errors of centering, were so obvious to him, that just before his

death he ordered a complete circle, of 6 feet diameter, to be made, with a telescope, of 4-inch aperture, fixed upon it, graduated around its periphery. This circle turned upon a pivot carried through a wall to which were fixed six micrometers for reading the circle divisions. Maskelyne did not live to use this "Mural circle," but Pond had the advantage of it; and he subsequently had another one made like it, using the two together. Pond also had a new Transit made by Troughton, of 5-inch aperture, which was a masterpiece; and with these means he pushed observing accuracy to a point that had not before been aimed at, and has even now scarcely been surpassed.

The essential parts of all these instruments (except Flamsteed's) are shown in the accompanying sketch, upon a scale of

FIG. 1.



ANCIENT GREENWICH INSTRUMENTS.*

1. Halley's Transit (1721–1749).
2. Bradley's Transit (1750–1816).
3. Bradley's Zenith Sector.
4. Mural Quadrant (1725–1812).
5. Troughton's Transit (1816–1850.)
6. Mural Circle (1812–1850).

about $\frac{1}{4}$ inch to the foot: the cut also shows the form of Bradley's famous Zenith Sector, with which he consummated his immortal aberration discovery.

The present Astronomer Royal, Sir George Airy, used Pond's instruments as he found them until about the year 1850, when finding them too small in their object-glasses for existing and future wants—especially for the observations of the newly-dis-

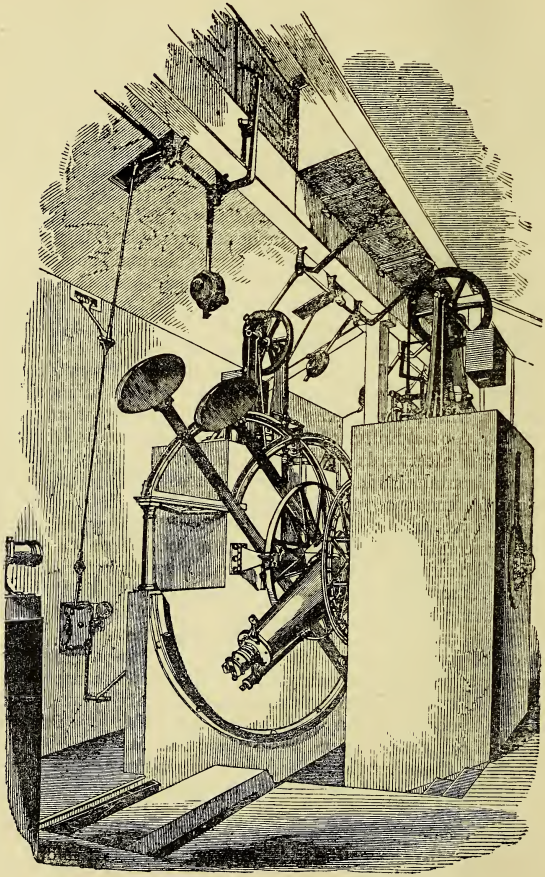
* The woodcuts illustrating this article have been kindly lent by Messrs. Bell and Daldy, and Messrs. Bradbury and Evans.

covered minor planets—he made a revolutionary change of double character, first, by designing an instrument which, while carrying a large object-glass, should in itself combine the functions of both a Transit and a Mural Circle, and second, by causing such an instrument to be constructed of a solidity hitherto undreamt of. The engineer became instrument-maker in place of the optician, and cast and wrought iron-work of the former supplanted the tender and perishable brass of the latter. Not that the optician was ignored, but his work was confined to the delicate parts, the glasses, micrometers, and divided circles; and he and the engineer worked upon this instrument, as in all later additions to Greenwich, in judicious concert under one head.

The Transit Circle consists essentially of a telescope, 12 feet long with an object-glass of 8 inches diameter, turning between two massive stone piers. The telescope tube and the pivots are of cast iron strengthened by internal braces. In the focus is the series of vertical cobweb wires, the central one marking the meridian, for observations in Right Ascension. Upon the western side of the axis (right hand in the cut) is a circle 6 feet in diameter, divided on silver to five minutes of arc, and read by six long micrometers whose eye-ends are on the other side of the pier, which is pierced for the purpose. The micrometers read to ·01 of a minute. The circle reads Zenith Distances, which are afterwards converted into North Polar Distances. One horizontal wire in the telescope, whose position is registered by a micrometer screw on the eye-piece, is used to bisect the star or object under observation, and the reading of its micrometer is combined with the circle reading. Upon the eastern axis (left hand in the cut) is another circle; this is for clamping only. A trough of mercury (for obtaining the horizontal point of the circle by observation of the same star directly and by reflexion) is carried on a circular tramway on the eastern pier by means of parallel bars which, with the counter-weights of the trough, appear in the picture: the trough does not appear. North and south of the instrument are two fixed inverted telescopes (the end of one appears in the cut); these are for giving a line of collimation: each has a wire at its focus which can be viewed by the other through an aperture in the central cube of the great telescope, or by raising the great telescope from its bearings, for which there is due provision; the wires are adjusted to coincidence, and then by observing each with the great telescope the collimation error of the latter is obtained. The instrument is never reversed. The error of level of the axis is found by measuring the amount of non-coincidence of the meridional cobweb with its own image reflected from a trough of mercury placed perpendicularly under the telescope.

In front of the observer, as he looks south, is the *Transit clock* (not seen in the picture) for observing times of passage

Fig. 2.



THE TRANSIT CIRCLE.

of objects over the vertical wires. Formerly these times were taken by ear, the observer counting the clock-beats and noting

the second and decimal of a second at which the object passed each wire. Since 1851 they have been registered by an electric chronograph. A sheet of paper on a cylinder rotating uniformly receives a puncture from a point on the armature of an electro-magnet at every beat of the Transit-clock: thus a time scale is formed by the clock. The observer taps a key mounted on the telescope eye-piece as the object under observation crosses each wire; his tap completes a galvanic circuit which works another electro-magnetic pricker; his punctures fall among the clock punctures, and their times can be read off thereby. The prickers travel down the cylinder as it rotates, and thus give a spiral line of registers. Uniform rotation of the cylinder being of the highest importance, it is secured by a driving-clock controlled by a *rotating* in place of a vibrating pendulum.

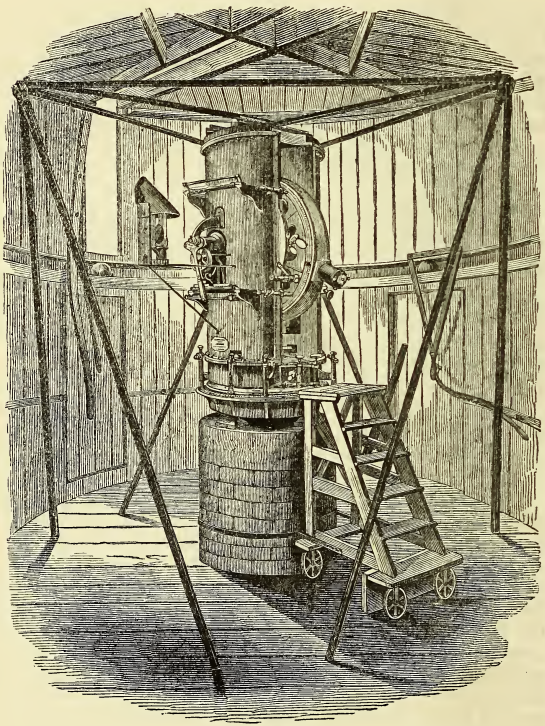
Since the *Transit-clock* is a measuring instrument of the most accurate kind, its excellence and the steadiness of its rate should be of the highest character attainable. The one in the Transit Circle room at Greenwich having grown old and exhibited some slight infirmities, a new Sidereal Motor has lately been mounted, in a basement where the temperature is nearly uniform, at a distance from the Transit instrument. It is, however, in connection with the chronograph, and nearly all Transit observations are made (galvanically) by it. It also gives controlling currents to several subsidiary clocks. Its rate is wonderfully regular; so uniform, indeed, that it faithfully exhibits the small changes which are produced by barometric fluctuations.

The Transit Circle being the chief instrument of the Observatory, it is in almost constant use whenever the sky is clear. A daily course of work with it includes Transits and North Polar Distances of the sun, moon (when visible on the meridian), all the large planets that pass before 3 o'clock in the morning, all the small planets passing between 10 P.M. and 1 A.M. during the first half of the lunation,* transits of a selection of the principal or fundamental stars for error and rate of the clock, an upper and lower culmination of a polar star for azimuthal error, an observation of the reflected meridional wire for level error, and of each collimating mark for collimation error of the Transit telescope; and observations of four stars, two north, two south of the zenith, each by reflexion and directly, for the horizontal-point error of the circle. These secured, as many extra or small stars as can be are observed for the ultimate formation

* By arrangement with the Paris Observatory the small planet observations are divided; Greenwich observing from new to full moon, and Paris from full to new moon.

of catalogues, or for special purposes. Certain instrumental errors, such as flexure of the telescope, errors of circle divisions, and want of circularity of pivots, are determined occasionally. Nothing is supposed for a moment to be in perfect adjustment;

Fig. 3.



THE ALTAZIMUTH.

no error is *mechanically* corrected; everything is supposed to be always wrong, and to be corrected *numerically* in the after reduction of the observations.

But the Transit Circle has an important auxiliary in the Altitude and Azimuth, or, as it is briefly called, the *Altazimuth* instrument, which was designed specially for position observations of the moon. Viewing the primary importance of these

observations, and having regard to the impossibility of seeing the moon on the meridian during that critical part of her orbit when she is near the sun, and also to the frequent loss of meridional observations from temporary cloudiness of the sky, Sir George Airy deemed it highly desirable to devise means of securing observations *off the meridian* comparable in accuracy with those made on the meridian. The only form of instrument competent for this purpose was an altazimuth of massive construction. He accordingly designed and mounted (in 1847) the instrument here figured. It consists of a telescope (4 inches aperture) solidly fixed into a broad-rimmed vertical or altitude circle which has a divided silver limb read by four microscopes. This circle turns between two semi-cylinders of cast-iron connected by top and bottom plates to form a frame which turns on vertical pivots, the lower one borne by a stone pier and the upper one by a triangular framework of iron bars. The vertical frame carries on one side the four microscopes which read the altitude circle, and around its base other four which read a horizontal circle fixed to the stone pier for azimuthal measures. There are levels for showing the inclinations of both axes; and they, and the microscopes, are carried by supports which are cast upon (not screwed to) the parts they spring from. The nightly observations with this instrument consist of an altitude and azimuth of the moon, azimuths of stars for zero of the azimuth circle and collimation error of the telescope, and observations of a distant terrestrial mark for zenith-point error of the vertical circle. All observations are made in two (reversed) positions of the telescope; and all times of exact position-determinations are registered by the chronograph. The azimuths and altitudes are in effect reduced to Right Ascension and Polar Distances by after-calculations, which are very laborious, but are, in common with every computation in the observatory, facilitated by skeleton forms of which about two hundred, simple and elaborate, are in constant use.

The Altazimuth secures about two hundred observations of the moon in a year, the Transit-Circle only one hundred; and a large percentage of the former are of the highest value as affording tests of the lunar tables for parts of the orbit when the moon is near conjunction with the sun, and cannot be touched by a meridian instrument.

Another auxiliary instrument of the exact class is the Reflex Zenith Telescope, for measuring with great precision the small zenith distance of the star γ Draconis, which passes near the zenith of Greenwich, and is favourably situated for determination of the amount of stellar aberration. It consists of a horizontal object-glass, capable of semi-rotation about a vertical axis, with a trough of mercury at half its focal distance below.

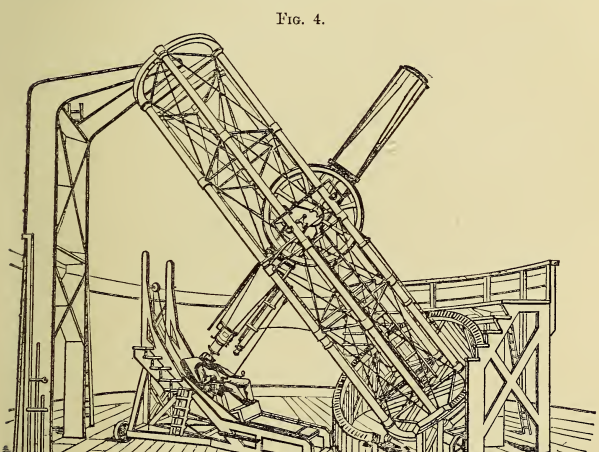
The rays from the star, after passing through the object-glass, are received upon the mercury and reflected up through the glass again, forming a focal image just above it. In the focal plane are the wires of a micrometer by which the star's image is twice bisected, the object-glass being reversed between the bisections. A measure of the star's zenith distance is thus obtained which is remarkably free from instrumental errors. During the past two years a zenithal telescope of 3-feet focus, filled with water, has been used upon the same star to determine whether the aberration is altered in amount by the passage of the star's light through a considerable thickness of a refracting medium—a question which has been raised by some continental astronomers. The observations hitherto have negatived the anticipated alteration.

Equatorially-mounted telescopes have always been regarded as of secondary importance at Greenwich. When Sir George Airy entered office he found the equipment in this department, to use his own word, "contemptible." The best equatorial then was one presented by Sir G. Shuckburgh, made by Ramsden, with a 4-inch object-glass, a shaky mounting, and in a very bad situation. In 1837 a $6\frac{3}{4}$-inch glass was presented to the Observatory by the late Rev. R. Sheepshanks; it was a somewhat inferior one, and it was mounted with circles too small for accurate measurements. So about fifteen years ago Sir George Airy planned the Great Equatorial, deeming it essential that the Observatory should have a first-rate instrument of the class, even if it was for a time regarded as a luxury. The instrument (without the covering dome) is figured in the annexed cut. Its object-glass, by Merz, of Munich, is of $12\frac{3}{4}$-inch aperture, and 17 feet 6 inches focus. The mounting is of the English form, which admits of large circles, and such were regarded as essential; the hour circle is 6 feet diameter, that for Declination 4 feet. The polar frame is formed of iron columns firmly braced, and connected at top and bottom by oval iron frames. Except the tube, which is of wood, every large part is of iron, and the whole was designed with the highest engineering skill. Gas is carried to all the micrometers about the instrument, and to the eye-piece; and galvanic wires are led to a chronographic touch-piece at the eye-end and to a chronometer there also, which is always in front of the observer at the telescope, and is controlled by the Sidereal Motor Clock. An observing chair, moving up and down upon a travelling frame, enables the observer to command all positions without leaving his seat. The driving-clock is mounted in a lower apartment; it consists of a water turbine controlled by a conical pendulum.

We have spoken hitherto solely of the tools of the Greenwich

observers. Let us now pass in review the works that have been actually accomplished thereby in furtherance of the objects for which the Observatory was constituted. We begin with the formation of star catalogues, for these are the foundations of exact astronomy. Flamsteed formed a catalogue of 3,310 stars, that remained the standard work of its kind for half a century, and has, in respect of selection and nomenclature of the stars it comprised, served as the basis of every catalogue since produced. Halley did nothing in this department. Bradley worked wonders; he laid the foundations of the present fabric

Fig. 4.



THE GREAT EQUATORIAL.

of mensurative astronomy. In 1750, when his new instruments were mounted, he began the daily course of meridional observations of principal stars, sun, moon, and planets which has continued without interruption (save by bad weather) to the present time. His star observations were incorporated into a catalogue (which comprised 3,222 stars) by Bessel, and, with values of the constants of refraction, aberration, precession, and other elements deduced therefrom, was brought forth by the illustrious Königsberg astronomer in a great work, whose title expresses its character—we allude to the "Fundamenta Astronomiæ." The rich harvest that Bradley reaped has not yet

had all its good grain thrashed out, for at this moment several German astronomers are engaged in a re-reduction of his observations, believing that they can get from them even more than Bessel obtained. Maskelyne did not aim at producing a great catalogue; he confined himself to thirty-six of the principal stars, whose places he sought to fix with the utmost possible exactness, in order that they might serve as reference-points of the first order. Pond accumulated a long series of observations, and produced a catalogue of 1,112 stars, which was the most valuable contribution to the sidereal astronomy of the time, and is second in accuracy to no modern catalogue. The present Astronomer Royal has already produced four large catalogues; the first from the observations during the twelve years 1836–47; the second from the six years 1848–53; the third from the seven years 1854–60, and the fourth from the seven years 1861–67. The numbers of stars in these catalogues average over 2,000 each; each contains all the fundamentals, and together they include the greater portion if not all the stars visible at Greenwich down to the fifth magnitude, and the majority of the sixth. They are sought all the world over, wherever accurate astronomy is pursued for its own sake or for geographical or geodetical purposes, and they have served and will serve again as the best materials for researches upon the proper motion of the stars or of the solar system.

Then as to the moon; Greenwich has alone sufficiently supplied the investigators of her movements from the time of Newton to the present. At so critical a period was the Observatory established that Flamsteed actually fed Newton, so to speak, from hand to mouth with places of the moon for perfecting the lunar theory which the latter was then deducing from his theory of universal gravitation; and there is an entry in Flamsteed's note-book of the author of the "Principia" coming down to Greenwich one Sunday evening for twelve observations of the moon of which he was in urgent need. Halley, though he did no star work, made some moon observations, and compared them with his own lunar tables; it was the only good piece of regular work that he did. He was the exception we previously spoke of to the consentaneous character of the Royal Astronomers; and his case shows that a man may be a great astronomer, and yet fail in the office of Royal Observator, which requires the exercise of no small amount of self-denial. The lunar observations of Bradley, Maskelyne, and Pond, have to be spoken of connectedly, for they were reduced *en masse* by the present Astronomer Royal, and they form the basis of the Lunar Tables that are now in almost universal use. But before this stupendous uniform reduction, the Greenwich Observatory had furnished 1,200 moon observations to improve

the tables of Mayer, which were the first generally available for nautical longitudes; 3,000 were employed by Burg for his tables, which so completely satisfied the conditions of a prize for such tables offered by the Consular Government of France, that the First Consul doubled the prize; and of the 4,000 which were employed by Burckhardt to correct the lunar elements for his famous tables (which served for nearly fifty years prior to 1862 as the basis for all navigational predictions), nearly the whole must have been derived from Greenwich.

The great lunar reductions previously alluded to embraced nearly 9,000 Greenwich observations of the moon, made between the years 1750 and 1830—a series without a parallel. The first fruit of their reduction was a general correction by Sir George Airy of the received elements of the moon's orbit. The next was the discovery by Prof. Hansen, of Gotha, of two inequalities of long period in the moon's motion, depending upon the direct and indirect action of the planet Venus. And what may be considered for the present as the ultimate outcome, was the construction by Hansen of the great Lunar Tables that bear his name, which represent the motions of our satellite with an accuracy surpassing all others, and abundantly sufficient for the preparation of reliable nautical ephemerides. Hansen's tables are used for all the important "Nautical Almanacs" of the world, with one exception, that of America, for which special tables were previously prepared, embodying, however, the corrections derived from the long suite of Greenwich observations.

If we look to other planetary tables, we find the same dependence for their data upon our National Observatory. The tables now used for Jupiter, Saturn and Uranus are those by Bouvard (1821), and they depend mainly upon the observations of those planets by Bradley, Maskelyne and Pond. The tables of Mercury, Venus, and Mars are Le Verrier's, based chiefly upon the Greenwich observations from 1750 to 1830, which were, with the rest of the planetary observations for that period, reduced by Sir George Airy *en masse*, like the lunar observations. For the sun, Le Verrier's Tables are also used; and they depend upon a century's Greenwich observations. The current tables of Neptune are those by Professor Newcomb, for which Greenwich found the major part of the observational data. Throughout the whole series of Planetary Tables that belong to the period of accurate astronomy, there is such a broad reliance for data upon Greenwich, and such comparatively small support derived from other places, that it is evident there was no excessive flattery in Baron Zach's assertion that our astronomical tables would have been as perfect as they are if no other observatory had ever existed. All this we adduce, not with the idea of glorifying a

national institution, but merely to aid the full conception of its mission, which was defined in Sir John Herschel's always happy words to be "to furnish now and in all future time the best and most perfect data by which the laws of the lunar and planetary movements as developed by theory can be, compared with observations."

It will be easily seen that with all things organised to this end there is little room for such work as double-star measures, celestial photography, delineations of planets and nebulæ, spectroscopy, &c. Some of these have occasionally been taken up for a time, but none of them have been, or indeed could be, systematically followed.

Of late, however, there has been a tendency in some subjects of this character to overrun the powers of attention of amateurs, to whom they have been left; and it has been suggested that inasmuch as they ought to be followed by the State, and Greenwich as at present constituted could not undertake the work, a special Observatory ought to be established and devoted to Astronomical Physics. The systematic record of solar phenomena (sun-spots, gaseous eruptions, &c.) has been mentioned as in immediate need of pursuit. Not unnaturally a counter question arose whether all that it was desirable for the State to undertake could not be done at Greenwich, and the Astronomer Royal laid his views upon the general question before the Board of Visitors at their meeting on June 1 last, in the following terms:—

"The tendency of late discoveries and consequent discussions in astronomy has been, not to withdraw attention from the exact departments of astronomy, but to add greatly to the public interest in those which are less severely definite. And this has become so strong, that I think it may well be a subject of consideration by the Board of Visitors whether observations bearing upon some of those trains of discovery should not be included in the ordinary system of the Royal Observatory. The criteria which, as appears to me, may be properly adopted in the selection or rejection of subjects of observation are these: Observations which can be made at any convenient times, which do not require telescopes of the largest size, and which do not imply constant expense, ought to be left to private observers. Observations which demand larger telescopes, and especially observations which must be carried on in continual routine and with considerable expense, can only be maintained at a public observatory. The claims of each subject must be separately considered; but there can be no doubt that a very powerful demand for attention is made when private persons have been induced to continue observations for a long time at considerable current expense, and when plausible

evidence is given of the connexion of results thus obtained with other cosmical elements. I think that these considerations exclude measures of double stars at the Royal Observatory, but they leave an opening for the scrutiny of nebulæ, planets, &c., and possibly (but I speak in doubt) of solar spectroscopy. But I have no doubt that they fully sanction the undertaking a continued series of observations of solar spots. The character of the Observatory would be somewhat changed by this innovation, but not, as I imagine, in a direction to which any objection can be made. It would become, *pro tanto*, a physical observatory; and possibly in time its operations might be extended still further in a physical direction."

Upon the effect of these statements it would be premature to speak. It is, however, generally understood that the Board decided upon the advisability of extending the Observatory system so far (for the present) as to include regular photographic record of solar spots and systematic solar spectroscopy. The Visitors are an intermediary body: before full effect can be given to their decision the Treasury must be appealed to for funds for the first cost of instruments and the running expense of an increased personal staff.

Chronometers have such a direct connection with navigation and sea-longitude, that not unnaturally Greenwich has been identified with the testing of these instruments from their invention to the present day; and now it is the chief depôt for Government marine chronometers. All business of their purchase, trial, and repair, is transacted at the Observatory; and usually about 200 chronometers are there under rating for issue to H.M. ships. Every year there is a competitive trial open to all makers, during which the chronometers are exposed to a wide range of temperature: four or six of the best instruments are each year purchased at good prices, and it is doubtless to these trials and to the general Government patronage of the trade that the supreme excellence of British chronometers is due.

Into the department of Time and its distribution we need not enter further than to say that a signal ball is dropped at one o'clock daily at the Observatory, and another ball at Deal is dropped by direct current from the Observatory; and that every hour accurate electric signals go forth from Greenwich, which are variously distributed over the country; one of them, that at 10 A.M., passing through well-nigh all the important telegraph lines in England. This department of the Observatory was, however, fully described in a previous number of the Popular Science Review (October 1870).

A magnetical and meteorolgical department was established in 1840, and till 1847 eye-observations of its instruments

were made every two hours, day and night. In 1848 photographic registration was introduced, and from then till now there has been an unceasing record of the movements of the declination, horizontal force, and vertical force magnetometers, as well as of the barometer and the dry and wet bulb thermometers. The anemometers, for direction, force and velocity of the wind, and also a pluviometer, register themselves mechanically. The magnetic observations and registers to 1863 have been discussed, and the epitomised results form the subjects of various memoirs in recent volumes of the *Philosophical Transactions*. It may be mentioned that among other points these discussions negative the existence of a decennial magnetic period related to the period of solar spot activity. A great discussion of temperature records from 1848 to 1868 is now in progress. Within the past few years an important, and we believe unique, addition has been made to the photographic recording department. The spontaneous galvanic "earth-currents" that at times become so intense as to interfere with telegraphic operations, have been made to record themselves perpetually by reflecting galvanometers connected with special wires running in N.-S. and E.-W. directions through the Observatory, and attached to earth-plates at their extremities. A discussion of some of the registers has shown that these currents are related to the earth's magnetism in its disturbed state —as during auroral displays—but apparently not in its tranquil state.

In conclusion, it should be stated that the Greenwich observations of all kinds are published in yearly 4to. volumes of nearly 1,000 pages each, in which every observation is set down in the utmost detail, with every instrumental reading as it is recorded by the observer, and (especially in the case of the astronomical observations) with every step in the reductions exhibited, down to the final results, which are given in such a form as to be directly available to the theoretical investigator.